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Environmentally Sustainable Concrete Curing with Coloured Polythene Sheets

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Abstract

Sustainability is imperative to the welfare and continual growth of society. Concrete is one of the most widely used sustainable construction material. It is persistently undergoing contemporary developments due to its versatility. Presently, sustainability in concrete is being achieved by several techniques including partial replacement of cement with supplementary cementitious materials like fly ash. These high-volume fly ash mixtures incite meticulous study of curing method followed. It would be also be of substantial significance to seek for an environmentally sustainable curing method that works equally well for conventional concrete mixtures and fly ash mixtures. The present study addresses curing of concrete with coloured polythene sheets. The coloured polythene sheets reflect/absorb/transmit solar radiation to concrete members in a definite fraction depending upon their thickness and optical properties. The vital objective of present study lies in identifying a curing method that supplies optimum amount of solar radiation to a concrete member for desired compressive strength development.

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1. Introduction

Concrete is one of the world's most widely used sustainable construction material. It is continually undergoing contemporary developments due to its versatility. Curing is the process of maintaining an

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optimum environment (temperature and relative humidity) around fresh concrete to promote proper cement hydration and strength gain. Hydration is a chemical reaction that occurs as soon as water and cement are mixed, but can continue for long periods. For this reaction to continue, concrete requires water. It is noteworthy that most freshly placed concrete contains considerably more water than required for complete hydration of the cement [1]. Curing has a strong influence on all important properties of hardened concrete such as durability, strength, water tightness, abrasion resistance, volume stability and resistance to freeze/thaw. Generally, concrete is mixed, cast and cured at a wide range of temperatures, and also remains in service at different temperatures. For the places like UAE, the actual range of temperatures has widened considerably due to extreme environmental conditions. This may affect the curing period required to achieve desired properties of concrete. On other side, it is highly advantageous to utilize the enormous amount of available solar radiations (or ambient energy) for the strength development process of concrete, which requires having knowledge of influence of temperature and other environmental factors on concrete.

In general, there is an increasing impetus on achieving sustainability in concrete construction. Several research works are underway to seek sustainable techniques for concrete construction. Naik [2] recommended that concrete industries must develop new techniques for creating concrete with minimal use of limestone. Jonkers *et al.* [3] investigated the potential of bacteria to act as self-healing agents for repair of cracks in concrete. Fonseca *et al.* [4] studied mechanical performance of concrete made with recycled concrete waste. A considerable amount of research has also been directed towards partial replacement of cement with supplementary cementitious materials like fly ash and ground granulated blast furnace slag. The process of curing as a sustainable approach would head to win–win situation.

All the operations of concrete manufacturing are energy intensive. Adoption of appropriate curing method can be sustainable approach as it advances towards the reduction of resource use. The duration and type of curing plays a big role in determining the required materials necessary to achieve the high level of quality. Curing is the process in which the concrete is protected from loss of moisture and kept within a reasonable temperature range. The result of this process is increased strength and decreased permeability. Curing is also a key parameter in mitigating cracks in the concrete, which severely impacts durability. When a smart, suitable, and practical curing method is used, the amount of cement required in achieving given strength and durability can be reduced by either omission or replacement with supplementary cementitious materials. Since the cement is the most energy intensive and commercially expensive portion of a concrete mixture, this leads to a reduction in the cost as well as the absolute carbon footprint of the concrete mixture. Additionally, being practical with curing methods can enhance sustainability by reducing the need for resource intensive conditioning treatments, should the curing method be incompatible with the intended service environment [5]. The present study proposes usage of colored polythene sheets as potential medium of curing. Curing of concrete structural members is carried out by covering them with different colored polythene sheets. These sheets have several advantages like they do not allow appreciable loss of water by evaporation and thus do not delay or prevent curing (or hydration process) besides providing optimal ambient energy (in terms of temperature, relative humidity, distance and orientation of surface receiving solar radiations, etc.,) for strength gain and sheets are readily available, reusable and can easily cover all surfaces of concrete structural members in building construction and infrastructure development.

The prime objective of present study lies in study of compressive strength and related parameters of M40 grade concrete. The concrete cubes cast were cured using five different colored polythene sheets (black, blue, red, white and yellow) to relate their response to compressive strength gain in comparison to conventional methods of curing (ponding and sprinkling). According to Kosmatka [6], in order to prevent damages in concrete due to volume changes, excessive rates of heating and cooling should be avoided. A higher curing temperature provides earlier strength gain in concrete than a lower temperature, but it may decrease characteristics compressive strength of concrete. Gardner [7] recommended that the period of time that concrete should be protected from freezing, abnormally high temperatures, and against loss of moisture depends upon numerous factors – type of cementing material used, mixture proportions, required strength, size and shape of the concrete member, ambient weather, and future exposure conditions. Therefore, identification of an environmental friendly curing method to suit prevailing environmental conditions is essential.

Most of the studies on the strength development, influence on mechanical properties, pore size distribution, and durability of concrete have been performed thus far involve standard curing conditions. A considerable amount of research work has been carried out in the field of membrane curing too. Most of this has been devoted to study the influence of curing on the properties of concrete, but the mechanism of membrane curing in retaining moisture loss has not been thoroughly investigated.

2. Experimental programme

Concrete grade of M40 with target compressive strength of 50.89MPa was used. SV Superplast was used as a super plasticizer to allow for water reduction in concrete mix as 0.3% by weight of cement content. The concrete cubes of size 150mm were hand rodded in three equal layers according to ASTM C31-91 [8]. All of the cubes were taken out of their moulds after 24±4 Hrs.

Table 1. Properties of M40 grade fresh concrete

Water/Cement	Compaction Factor[#]	Average slump[#] (mm)
0.305	0.75	38

[#] Compaction Factor and slump were determined for all the mixtures and average has been reported

For each curing method three cubes were cast and average has been considered for analytical results. Curing through ponding was achieved by immersing the cubes in water tank for the entire period. For curing through coloured polythene sheets, cubes were wrapped with polythene sheets so that all the surfaces are sealed properly to lock the moisture. Polythene sheets used for present study confirmed to ASTM C171 [9] .To study the influence of solar radiation on characteristic compressive strength (CCS) of concrete, the cubes were cured for period of 3– and 7–days, and compressive strength was determined at a period of 28 days. For determination of compressive strength, all the cubes were tested in compression testing machine having a 2000kN capacity. The cubes were tested such that line of action of the load is at right angles to the axis of the cube as-cast. The quality assessment of concrete cubes cast was carried out using non-destructive method of testing viz. ultrasonic pulse velocity method. For present study, the pulse velocities of cubes lie in the range of 4793 to 5013 m/sec with average value of 4895m/sec which indicates an acceptable quality of concrete cubes cast in accordance with BS 1881-201:1986 [10].

3. Transmittance of solar radiation through different curing media

3.1. Transmittance of solar radiation through curing media

Transmission of the incident solar energy through transparent medium is a function of the type and thickness of the medium, the angle of incidence, and specific wavelength bands of radiation. Coloured polythene sheets are used as curing medium for present study. These polythene sheets reflect/absorb/transmit the available solar energy in a definite proportion depending upon their optical properties and thickness. The concrete cubes absorb only portion of solar radiation transmitted by polythene sheets. Transmitted solar radiation is determined on basis of coefficient of transparency of a polythene sheet using spectrophotometer. Thickness of sheet has been kept constant for the study, so development of compressive strength completely depends upon colour of the polythene sheet. A plot of transmittance vs. wavelength of light for air, water and different colored polythene sheets called transmittance spectrum were drawn using spectrophotometers. Fig. 1 shows transmittance spectrum within the wavelength range of ultraviolet and visible region for red color sheet. It was found that air transmitted all 100% of incident radiation, therefore it resumed coefficient of transmittance as 1. For other curing media relative coefficient of transmittance is calculated by subtracting area under the transmittance spectrum of a particular medium from area under the transmittance spectrum of air. It was observed that black polythene sheet transmits minimum amount of incident radiation.

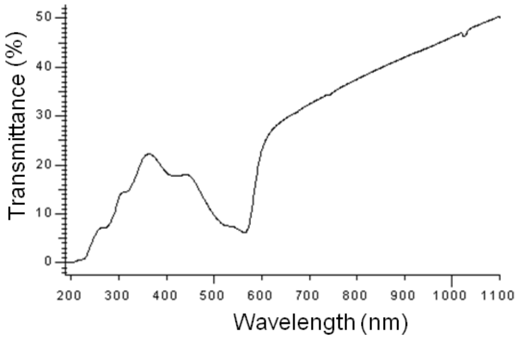

Fig. 1.Transmittance spectrum for red polythene sheet within ultraviolet and visible region wavelength

3.2. Solar radiation on earth's surface

Solar radiation received at the top of the earth's atmosphere on a horizontal surface is called the extraterrestrial radiation. The local intensity of radiation is determined by angle between the direction of sun's rays and the normal to the surface of the atmosphere. This angle will change during the day and will be different at different latitudes and in different seasons. Extraterrestrial radiation is thus a function of latitude, date and time of day. The values of daily extraterrestrial radiation (i.e., solar radiation in $kJ/m^2/day$) reaching the surface of earth are calculated for days concrete cubes were exposed to atmosphere.

Total solar radiation absorbed by cubes is calculated as sum of solar radiation for number of days these cubes were cured and for number of days for which the same cubes were exposed to environment. This ensures that concrete cubes cured through sprinkling received maximum amount of solar radiations, while cubes cured using black polythene sheet received minimum amount of solar energy. Consequently, these cubes were subjected to a wide range of solar energy to study role of available solar radiations in development of compressive strength. It is also evident that cubes cured for a period of 3–days received more solar radiations than cubes cured for a period of 7–days, as the former cubes were exposed to environment earlier.

4. Influence of available solar radiations on curing method

It is quite well known that environmental conditions play important role in development of compressive strength of concrete [11]. Concrete requires an optimum temperature and optimum amount of ambient energy to ensure proper rate of hydration. In present study, concrete cubes were subjected to solar radiations ranging from 0.00054×10^7 to 1.1593×10^7 $kJ/m^2/day$ as a result of varied climatic conditions, curing periods, and different curing methods adopted. It was observed that available ambient energy influences various curing methods used and consequent compressive strength of concrete.

150 mm cubes of M40 grade concrete mix, cured for 7–days, compressive strength determined at 28–day, resulted in absorbed solar radiations of 0.0087×10^5 kJ to 1.14×10^5 kJ as seen in Table 2. Similar cubes when cured for 3–days resulted in higher range of absorbed solar radiations of 0.0062×10^5 kJ to $1.36\text{x}10^5$ kJ as seen in Table 3. Cubes cured using red polythene sheet for 7–days produced higher compressive strength as they absorbed higher proportion of absorbed solar radiations of the order $0.1834\ \text{x}10^5$ kJ. A similar trend of strength development was observed when cubes were cured for 3-days with absorbed solar radiations of $0.1316\ \text{x}10^5$ kJ.

Table 2. 150 mm Cubes of M40 grade with curing period of 7–days, compressive strength determination at 28-days

Curing method	UPV (m/s)	Solar Radiation (10^5 kJ)		Avg. Comp. Stress (MPa)	Standard Deviation	Coeff. of variation (%)
		Without Curing	With Curing			
Sprinkling	4947.96	1.1451	0.3782	52.18	0.68	1.31
Ponding	4947.03	1.1451	0.3419	51.31	0.42	0.82
Red	4887.92	1.1451	0.1834	54.76	0.26	0.48
Yellow	4917.15	1.1451	0.0571	50.65	0.27	0.52
Blue	4887.62	1.1451	0.0514	54.28	0.10	0.18
White	4956.04	1.1451	0.0813	50.66	0.22	0.44
Black	4918.03	1.1451	0.0087	49.17	0.67	1.36

Table 3. 150 mm Cubes of M40 grade with curing period of 3–days, compressive strength determination at 28-days

Curing method	UPV (m/s)	Solar Radiation (10^5 kJ)		Avg. Comp. Stress (MPa)	Standard Deviation	Coeff. of variation (%)
		Without Curing	With Curing			
Sprinkling	4840.82	1.3642	0.2714	51.64	0.59	1.1
Ponding	4837.85	1.3642	0.2453	50.79	0.94	1.8
Red	4888.48	1.3642	0.1316	53.10	0.62	1.2
Yellow	4870.13	1.3642	0.041	50.39	0.43	0.9
Blue	4885.99	1.3642	0.0369	51.89	0.65	1.2
White	4901.96	1.3642	0.0583	50.33	0.96	1.9
Black	4879.11	1.3642	0.0062	48.97	0.56	1.1

The above experimental results are summarized as seen in Fig. 2. It can be clearly seen that compressive strength development has happened in proportion to the solar radiations absorbed concrete cubes. The cubes absorbing higher proportion of incident solar radiation produce higher characteristic compressive strength. However, this should be seen as a function of several other environmental factors like wind velocity, relative humidity, average maximum and minimum temperatures, as extended scope of work. Despite the fact that, the solar radiations absorbed by cubes cured thorough sprinkling and ponding are higher (than cubes cured using polythene sheets) but the incidence of evaporation of water in sprinkling method and amount of water consumption especially in water scarce areas in ponding of concrete structural elements cannot be neglected. Pouring water over concrete elements that have not completed its setting process could adversely affect hydration process and alter concrete characteristics.

Therefore, it is evident that curing through colored polythene sheets results in varied magnitude of solar radiations available to concrete members. These solar radiations in an optimal proportion can be utilized for completion of hydration in absence of any additional water required for curing. Also, in order to achieve higher compressive strength, an optimal proportion of solar radiation is required in existing environmental conditions.

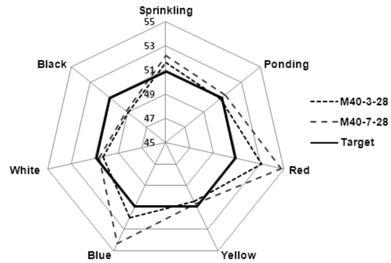

Fig. 2. Influence of various curing methods on average CCS of M40 grade concrete cured for 3– and 7–days

5. Conclusion

Solar radiations in an optimal proportion can be utilized for completion of hydration in absence of any additional water required for curing. Black sheets are found to have least value of coefficient of transmittance; it absorbs all the incident solar radiation, and hence can be used during cool climatic conditions and interior locations. While, curing through red, blue and yellow polythene sheets produce higher compressive strength in higher values of solar radiations, as they reflect higher proportion of solar radiations.

It is expected that at higher temperature, more transmittance result in speeding up the chemical reaction of hydration, which can be achieved through curing using red, yellow and blue polythene sheets. As these colors reflect higher proportion of solar radiations, while black absorbs the entire solar radiation incident upon it, curing through black colored polythene sheets could be useful at lower temperatures.

There exists definite relation between the prevailing environmental conditions and ambient energy released by solar radiation received on earth's surface. A linear relationship between average temperature during the day and solar radiation received on earth's surface can also be proposed. In this manner, having known the solar radiations transmitted by a particular curing technique, the amount of solar radiations absorbed by concrete cubes cured thorough that particular curing method can also be determined.

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